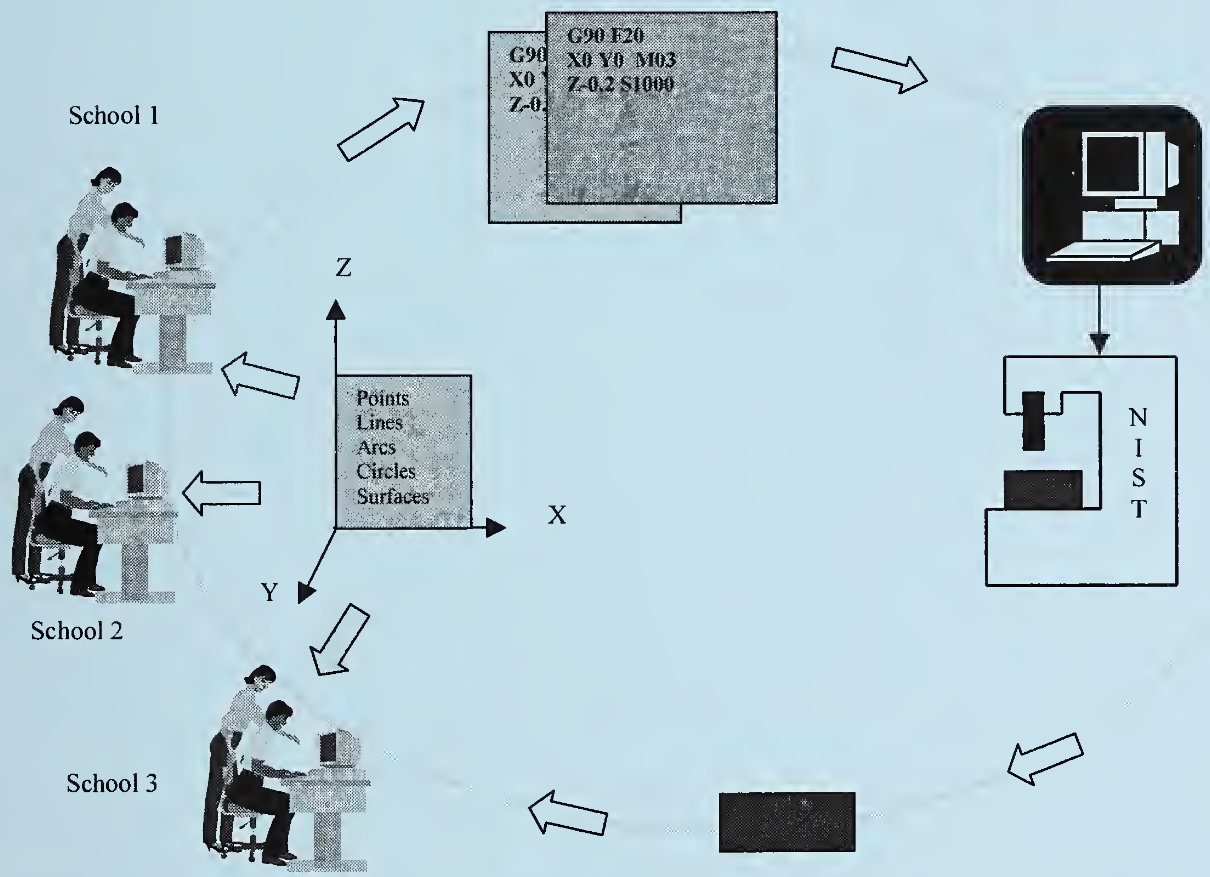
NISTIR 6313

Manufacturing Technology Learning Modules—Sharing Resources for School Outreach

C. Denver Lovett



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Manufacturing Technology Learning Modules—Sharing Resources for School Outreach

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Disclaimer

Company names and commercial products are sometimes mentioned in this report. The mentioning of company names and commercial products is not an endorsement. This report also contains photos of products. Likewise, the appearance of the photos displaying software and products does not represent an endorsement.

Table of Content

1.0 Introduction

1.1 Overview:

The Manufacturing Technology Learning Modules (MTLM) Project was started in 1992. Several prototype modules[1] were developed and tested. Two of the modules are commercial grade products. Three other modules are prototypes. These three prototype modules were developed in response to solicitations of Small Business Innovation Research (SBIR) Program. Although these modules were developed under Phase 1 SBIR solicitations, the demonstration of the products revealed some outstanding accomplishments, considering Phase I was a six-month feasibility study. Although the work on these modules was terminated because of the lack of follow-on funding, some of the tutoring concepts deserve revisiting if funds are available. A brief explanation of modules, and the need for improving existing modules and to develop new modules is given in Section 7.0

The main focus of the MTLM Project is the use of a manufacturing theme to integrate math and manufacturing technology within schools. The central module within this theme is a Machining Simulation software package developed by Volcancraft, Inc (see the disclaimer statement at the front of this document on page ii). This focus and these modules were chosen because of the following attributes:

- Provides a conceptual visualization of geometry within three-dimensional coordinate space
- Provides an easy way to integrate math with technology
- Helps in the achievement of some of the math educational standards
- Helps to relate math to practical manufacturing application
- Provides a way to show-off a student's accomplishments, and this builds self-esteem
- Provides insights for future careers

This document is intended to accomplish the following: (1) explains the operation of the MTLM project, (2) describes the equipment and the software that is used to implement the MTLM process, (3) shares comments that were provided by people from industry, (4) shares two teachers' perspectives on this project, (5) shares the writings of the participants in a fourth grade math club who wrote very enthusiastically about the importance of the math club to their learning, (6) shares comments of parents (7) suggest

[1] A module is a software unit that uses applications for integrated learning of math, science and other disciplines.

some conduits to future career paths for student participants in the MTLM project, and (8) offers some opportunities for future uses and future project developments.

1.2 Background

Over the last four years, the Manufacturing Technology Learning Modules (MTLM) project has operated at the Math Club at the Clearspring Elementary School and at Thomas Jefferson High School of Science and Technology (TJHST), in Alexandria, Virginia. Other Washington metropolitan schools have also participated in this project. However, primary focus here is on the Clearspring Math Club and TJHST. Each year the successes of this Math Club far exceed the expectation of the instructor, parents, and the project Developer at NIST who operates the Manufacturing Technology Learning Modules project. The project was conceived to accomplish the following objectives:

- Demonstrate the application of math to manufacturing
- Introduce students to design, programming, and machining
- Influence local schools' curriculum with a manufacturing emphasis
- Create intern opportunities for high school students
- Strengthen NIST ties to local schools

The success of this project can be attributed to the technology and the effective interaction of the people involved in this project. Each will be discussed in the section below.

2.0 Effective Interaction

A good match between the technology and the people that work with technology is very important in initiating a school outreach project. On the receiving end, the teacher has to be receptive to innovation and be being willing to experiment with new concepts for learning. The school's administrator should be supportive of the teacher in the experiment. In the case of the Math Club, we had effective networking of NIST colleagues who saw the value of this project and were willing to provide referrals to teachers that were "open" to new technology. The teacher and the principal made an initial visit to NIST to view a demonstration of the software and hardware of the MTLM project. This demonstration stimulated initial interest in this project.

The interactivity of the Math Club at Clearspring Elementary School is a factor that contributes to the successful operation of this project. The school's selection process for club membership requires the submission of an application (see page C-1 of Appendix C). Within the application, the student is asked to write a statement explaining reasons for wanting to participate in the math club and sign a pledge of commitment. Usually, twenty 4^{th}-grade students are selected to participate in the math club. The selection is based on the stated objectives and a pledge of commitment of the student and parent. To

participate, the students must agree to attend two times per month during the recess period.

The ongoing activities between NIST and the Math Club include the following:

- Annually, a NIST staff visits the classroom at the school to give a talk to the math club.
- Math club and about three parents visit NIST to see a demonstration of hardware and software in the MTLM Lab, usually two times per year.
- In cases when an Internet connection is not available, chat sessions are held between students and NIST Staff, using MODEM connections between the computer at the school and the computer at NIST.
- Training sessions for teachers are conducted by the NIST staff.
- Technical problems are solved as the need arises.
- A parent of a former student, who volunteered to work as a NIST guest researcher to this project, developed Web pages for this project. The URL for this Web pages is: **http://www.mtlm.nist.gov/**

The user-friendly interface for the equipment and software promotes effective interactions among students and between students and their teacher. Initially, a student can produce results that are very satisfying, with a minimal up-front effort. This ease of use and almost instant visualization of their results, generate excitement and greater interactions among their peers and with their parents. The technology and some of the processes involved in this MTLM Project are discussed below.

3.0 MTLM Technology & Process

The technology is simple to understand and serves as a motivating factor for the students. Students are fascinated by their abilities to exercise control over the machine that performs the movements required for machining their projects. The designs start with the students' visual concepts of something that they really want to make. The students further conceive their designs as a combination of geometrical elements, such as connecting lines, arcs, circles and points that define the start-point and end-point of lines and arcs and the center point of circles (see Figure 1). This process of combining geometrical elements to replicate a student's mental model is a synthesizing process and it is performed on two-dimensional, coordinate graph paper. After precisely sketching the design on graph paper, the student plans the sequence of machining operation, that is, which machine movements are executed first, second, third, and so on. This planning of the order of machine execution is called process planning. Although the design for the project is plotted on two-dimension graph paper, the machine execution is performed in

three-dimensions. This requires the student to think in three-dimensions. Once the order of movements is decided, the student uses the coordinates of the design to write the machine-motion commands. These motion-commands together with preparatory commands and a few miscellaneous codes form the essential parts of a Numerical Control (NC) program. The NC program contains a collection M&G code (See Table 1).

To help students visualize the machining action for each line of code, the student enters each line of code into machining simulation software. This software helps the student in verifying the correctness of the geometry of the design by visually simulating the NC programmed motions of a three-axis milling machine (see Figure C7 of Appendix C). In Figure C7 of Appendix C, the student and teacher observe the simulated machine actions commanded by each line of code. The student verifies either a single line or a group of lines of code at a time. All of the above activities usually take place at the school site, and also sometimes during the Math Club visits to NIST (See Photos in Appendix C).

Figure 1 diagrams the operation of the Manufacturing Technology Learning Modules at the school site and at NIST. In Figure 1, the activities above the horizontal centerline occur at the school, and activities below the centerline occur at NIST.

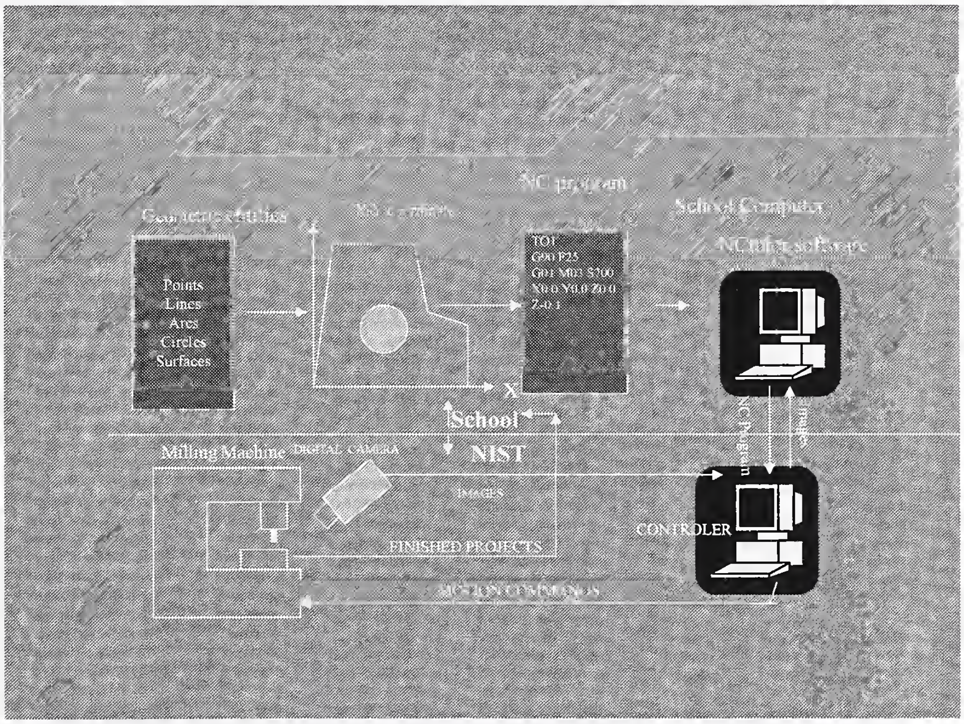

Figure 1: Flow Chart of Operation for MTLM Project

At NIST, there is one, three-axis milling machine, a computer used as the machine tool controller, software for controlling the machine, software for verifying the correctness of the program, an NC editing program for correcting any errors that are detected during the verification, and a digital camera that records still images of the wax-block that is being

machined. Some of these components of the MTLM project are shown in Figure 1. More detailed descriptions and views can be found in Appendix A and Appendix B.

The numerical control programs from students are often received at NIST over the Internet as a packed-file attached to an e-mail message. The packed-file is unpacked into individual files that are loaded into the machine tool controller (a 486 computer), and these files are again verified by the verification software that is running in the machine tool controller. Blank, wax blocks are placed into a vise that clamps the block to the table of the milling machine. Setup procedures are conducted to position the machine to the origin of the block's coordinate system. This is often called the part coordinate system. Another operation is performed which causes the machine to recognize the coordinate system of the block. This operation is called zeroing the machine. After these operations are performed, the machine is commanded to run the numerical control program. The machine tool controller, shown in Figure 1 and in Appendix B (Figure B4), processes each line of NC code and converts these lines of codes into execution commands. These commands, which are either motion commands or preparatory commands, are sent line-by-line to the machine tool for execution. Digital images are usually taken during pauses of machining and after the machining operations for work-parts are completed. These images are captured from the digital camera and transmitted to the school site via the Internet as an attachment to an e-mail message. At the school site, these images are retrieved by clicking on the attachments to the e-mail message.

Figures 2 and 3 are examples of the digital images. They were taken after the machining operations on the two wax-blocks. Two students of the Math Club wrote the NC programs for the machining operations of these wax blocks (see Appendix C). The Math Club is held at Clearspring Elementary School in Damacus, Maryland.

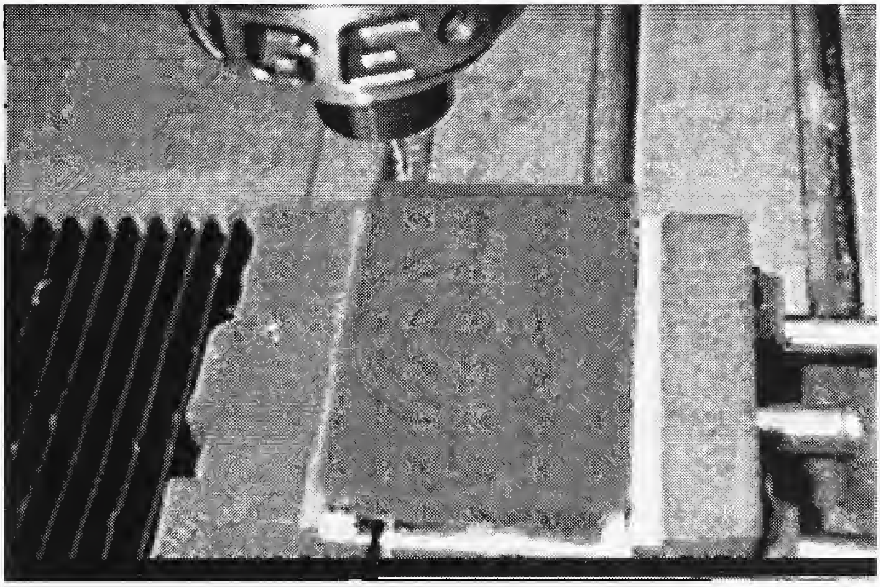

Figure 2: Milling Machine, Vise and Machined project

Figure 2 shows the milling machine and the vise. Some of the components of the milling machine are displayed in Figure B1 of the Appendix B. These digital images could provide a simulated view of the machining environment. A view of the machining environment is important for understanding how to control the tool so as to avoid driving the tool into the vise or other obstructions in the work environment. Figures B1 and B3 of Appendix B provide other views of the machining environment. Table 1 shows a few lines of NC Code that were used to generate some of the arcs shown in Figure 2.

Table 1: Selected Lines of NC Code from Design in Figure 2

```
T1
G0X0Y0Z0.1F25.0M03 S2500
X1.2Y1.0
Z-.1
G90
G2
X1.8Y1.0I1.5J1.0
G1
Z.1
X2.0Y1.0
Z-.1
G90
G3
X1.0Y1.0I1.5J1.0
G1
Z.1
 *
```

*NOTE: The completed program is shown on page C-2 of Appendix C

The following as an explanation of the NC Programming Code:

NC Words	Description	Typical Example
1. Dimension words	Specify the coordinates of a tool path	X1.2 Y1.0 Z-1.0
2. Arc center words	Indicate coordinate of an arc center	I1.5 J1.0
3. Preparatory words	Command a specific type of move	G0 G90 G2 G3
4. Feed Word	Specifies speed rate of machining	F20
5. Miscellaneous words	Indicate control mode such as Stop spindle or change tool	M03 M06
6. Spindle word	Specifies spindle rotation speed	S3000
7. Tool word	Indicates the selected tool number	T1

The machined block shown in Figure 3 is clamped in the vise and the vise is bolted to the table of the milling machine (See Figure B1 of Appendix B and Figure C3 of Appendix C). This Photo was taken after a machining operation. The machined wax blocks are referred to as the student's project. The students' projects vary in type. Some are engravings as shown in Figure 3; others are interesting designs such as shown in Figure 2.

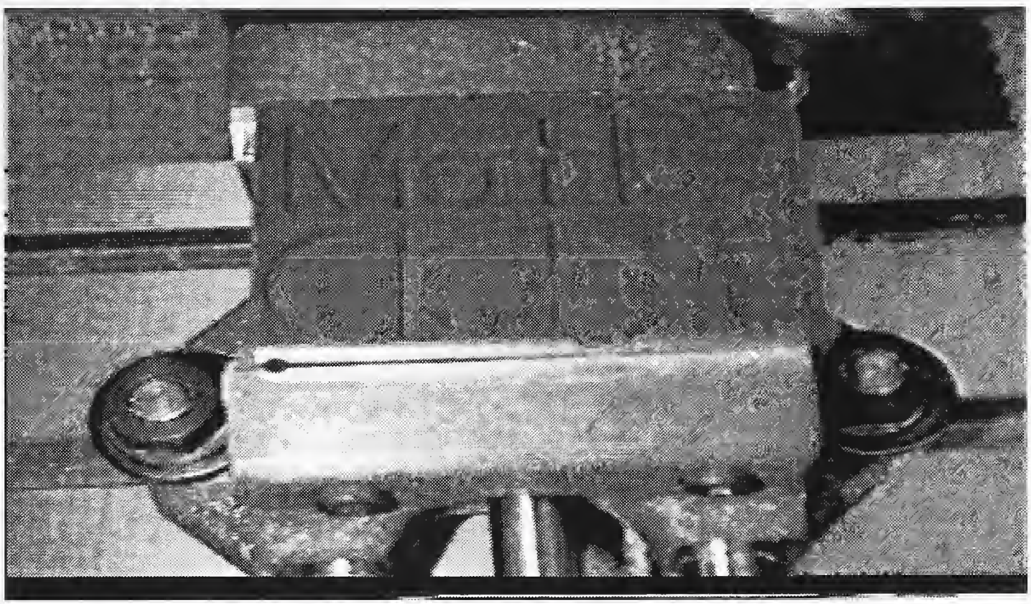

Figure 3: Machined Wax-Block of a Student of the Math Club

These designs range in complexity from simple engraving of text to geometric shapes that reflect various images created by the students. Figure 2 and several figures in Appendix C are examples of these designs. The engraving often makes a statement about something that the student feels strongly about, such as "Queen MOM or Super Dad ". It clearly comes through,-- that these students are excited about demonstrating their newly acquired knowledge to their parents as well as to their peers. The desire to demonstrate their knowledge is important, in that, these processes of making real things builds self-confidence and demonstrate how math applies to manufacturing processes.

Evidence of the students' accomplishments and excitement are provided by written comments from teachers and students, given in Section 4.2 and 4.3 respectively.

4.0 Comments and Critiques of the MTLM Project

To assess the effectiveness the MTLM project with respect to the objectives given in Section 1.2, participants were requested to provide a critique. These participants

consisted of two teachers and the students from the math club. In addition, to obtain an industry perspective on this project, two people from industry and one person from the machine tool trade association, the Association of Manufacturing Technology, were asked to provide comments and suggestions on this project. The comments are given below.

4.1 Views From Industry

Some industry people were requested to make comments on the value of this MTLM project with respect to future careers and education. The following quotes were extracted from responses of the three industry people:

4.1.1 General Motors Corporation, Machining Systems & Equipment Group
Comment [1]:

"In my opinion this program should be expanded to more schools across the country. There are obvious benefits to such a program; it familiarizes young students with manufacturing technology and demonstrates how math and science are integral parts of the manufacturing world."

"....The use of classroom computers to build an NC program and the use of the Internet (to transmit the NC program) and finally see the fruits of students'work is a powerful method to draw students' interest in manufacturing."

Suggestions for Improvements:

" ...I would suggest that for higher-level high school students, the program examples should include 3D surfaces, constructed by using curve surfaces which the student would construct by using curve lines with high degree mathematical functions. This exercise would show the students the power of the mathematics coupled with manufacturing technology as a means of generating complex forms as seen, for example, in the automotive industry (car's outer body) or other industry (wings and other 3D surfaces).

"Another suggestion would be to organize friendly competitions among the schools where the MTLM program is implemented and show-case the winner during trade shows such as International Machine Tool Show."

4.1.2 Link Gear & Machine Company:
Comment [2]

"In my opinion, your project provides access to manufacturing technology at the K4-K12 level is a worthy objective. Higher levels of technology such as computer-aided design and computer-aided manufacturing (CAD/CAM) applications and computer numerical control (CNC) Machining are common in today's manufacturing environment. Without these technologies and the skills to operate these technologies, manufacturers are simply unable to compete in the local markets let alone the international market".

"Our manufacturing sector needs to apply increasing amounts of math-based computer technology, computer controlled design and machining technology to succeed in the future. Changes in design programs are occurring at a rapid pace. Needless to say, being on the cutting edge of technology is necessary to compete, but unless we have the workers, engineers and mathematicians knowledgeable of the modern technology, all is for naught."

"Although I am not in a position to technically evaluate your Manufacturing Technology Modules project, the concept of transferring these training modules to educational institution via the world-wide Web is exciting and progressive. Up- to-date manufacturing hardware and software is very expensive and difficult for the schools to afford on their own. Your project would provide access to technology to their classrooms at the expense of a PC, MODEM, or Internet connection."

"The manufacturing sector has a severe shortage of technically trained, skilled workers and engineers. These careers seem to be increasingly overlooked as career paths, but they are critical to our future national competitiveness. Your project, introducing these options at an early age of education, should receive the encouragement and endorsement at all levels of industry, as we all wonder where we will find technically skilled work force in future generation.

"In conclusion, as a small manufacturer who depends on highly skilled workers, I believe the Manufacturing Technology Learning Modules Project has tremendous potential and should be pursued to introduce and educate students about the manufacturing sector, its new image and job opportunities [2]".

4.1.3 The Association for Manufacturing Technology Comment [3]

". . . In my opinion the problem lies in the tough classes which these young people have to take and the tough exams they have to pass. Many youngsters are turned off by simply listening to these arguments, without examining their abilities and testing their talents. It is for these reasons that I think that it is important to expose young minds to the basics of manufacturing technology at an early age to dispose preconceived fears in those with the necessary talent.

I, therefore, support NIST's effort in hope that at least some of these young people will recognize their natural abilities and decide on manufacturing technology-related profession as their vocation" [3].

4.2 Teachers' Perspectives

The teachers of K-4 through K-10 expressed a great deal of enthusiasm for the MTLM project. These teachers believe that this project is meeting the goals and objectives the

project was intended to achieve. The following are some positive responses that were extracted from the teacher's end-of-year report.

4.2.1 Observation from a teacher from Thomas Jefferson High School of Science and Technology[4]**:**

- For Technology education program throughout the school, the manufacturing technology for freshman has given a big boost to our advanced labs such as robotics, prototyping and energy report higher enrollment.

- Students are better prepared to take on advanced projects involving computer control equipment.

- One female student told her teacher that the introduction to the world of technology motivated her to pursue engineering and she received a scholarship at an engineering school.

- The MTLM project motivated some of the teachers to reclaim some Spectralight milling machines that were not being used and put them into action of machining wax-blocks.

- Teachers reported that students were frequently anxious about receiving their machined wax-blocks; continually asked about receiving their projects every day.

4.2.2 Observations from a teacher of the Math Club at Clearspring Elementary School [5]**:**

- ❑ Through Manufacturing Technology Learning Module partnership with NIST, my students have enhanced their math skills in the following areas:
    - coordinate graphing
    - decimal fractions
    - geometry
- ❑ Students have enhanced their technology skills in the following areas:
    - programming
    - keyboarding
    - computer-aided machining
        - ♦ write a numerical control (NC) program for directing a milling machine to manufacture a part
        - ♦ use machining simulation software to verify the correctness of the NC program

- ❑ As a result of their participation in the Clearsprings' Math/Technology Club, my students have also benefited in the following areas:

    - Creative thinking has been enriched and extended by students having to conceptualize and create designs.

- Fine motor skills development,-- students learn how to use and manipulate a compass, ruler, and programming grid.

- Develop interests in pursuing careers in manufacturing, engineering, math, and science; by their positive exposure to these fields at NIST have been very motivational (viewing governmental workers using design technology to solve problems).

- Increased self-esteem in math and technology as exhibited by the pride they show when their self-designed "blue blocks" are returned from NIST.

- Healthy social and intellectual interaction with their peers in doing projects- Students share programs and strategies.

- This has been a terrific "real world" application

4.3 Math Club Students' Perspectives

To get the fourth grade Math Club students excited about writing about the importance of the math club and why it should be continued, the teacher proposed a hypothetical situation to the students. If your teacher or principal were thinking about discontinuing the math club, could you write a paragraph to explain how important the activities of the math club is to your education? The students were asked to write a few paragraphs to explain how important this project is to their education. Fifteen students wrote paragraphs to defend this project. The writings of six students' [6] are given below:

> "Math Club teaches us coordinates and graphing. Before the math club I hardly knew anything about coordinate graphing. Also it teaches us about decimals. When we make circles and arcs, that teaches us about geometry. Math club teaches us a lot about computers. Before the math club I hardly knew anything about computers. Now I know a lot more about them. So please don't stop the activities of math club."

> "Math Club is important to me because it teaches us a lot of stuff that will help us when we grow up; things like coordinate graphing, decimals and geometry. The math club lets us experience the type of work that is done in engineering, math, science and computers. From these reasons above, you can see that the math club is very educational and fun at the same time. Please don't take the math club away."

> "Math club is important to me because it teaches me about coordinates and graphing, as we draw our designs and write our programs. It also teaches us about decimal and geometry. We learn about careers in science and technology. Our

> Math club is fun and interesting; that's why the math club is important to me, so please don't take it away from me."
>
> "Math Club is important to me because it is educational and fun in lots of ways. It teaches us math because we use decimals for coordinates and graphing; and it teaches us geometry too. Most of all, the math club is fun and I don't want to see it closed down."
>
> "Math Club is important to me because it gives us a lot of fun work. Typing the commands is work, but also a lot of fun. It lets us learn about careers in engineering, math, science and computers. It teaches us coordinates, graphing, decimal and geometry."
>
> "I really enjoyed working with the computer to create the blue block projects in Math Club. I learned a lot about how coordinate systems are used by computers to build things. I also enjoyed the field trips to NIST to see how the blocks were made. I feel the experience has made me a better student in both math and science.

In addition to the comments given above, ongoing communications with the teachers reveal facets of learning as described in Section 5.0 below. In addition to the students and teachers views on the MTLM project, two parents offered their comments on this project. These comments are given in Section 4.4 below.

4.4 Parent Perspective

"I felt that this program offered my daughter an opportunity to learn how computers are used for practical purposes beyond homework and games. I noticed that she was forced to think three dimensionally and figure out how to translate an idea on paper to the computer and ultimately to a blue block. She demonstrated as much enthusiasm for this effort as anything she ever worked on in school. In the long haul, this project has contributed greatly to her efforts to use technology for personal and school projects."
--Dave Hillman, parent of a former student in the Clearspring Elementary School Math Club

"Caity's experience in the Math Club including the Manufacturing Technology Learning Module Project has provided her with a great opportunity to learn and apply basic thinking skills which include how to conceive, create, and implement a logical sequence of actions which leads to a desired outcome. Having a tangible outcome (a block with her design cut into it) is a tremendous incentive to her. I also suspect that she feels a lot of prestige from being able to work with NIST, generating even more incentive. As a parent, I could not create a learning opportunity for Caity that would teach her the same basic thinking skills, which would also interest her as quickly or as deeply. I know that Caity has enjoyed the Math Club. It has opened up possibilities to her that she might not have been motivated to explore."
—Alfred E. Corey, a parent of a current student of the Clearspring Elementary School

5.0 Facets of Learning

Students involved in the MTLM project will be strongly motivated to learn new things about software, programming, machine tools, and tooling. Students extend their knowledge of coordinate systems, tooling, interpolating between the grid lines on graph paper, and using decimals. All these facets of learning are brought together to conceive a design in three-dimensional coordinate space. These activities are helpful in accomplishing the math educational "Standard 3: Geometry and Spatial Sense" and "Standard 4: Measurement [7]. Students learn some of the basics of the machining processes. For example, a student quickly realizes that the diameter of the tool is important because the coordinate position commanded by each line of code is the center point of the tool and all tools have thickness. Although the center point of the tool is important for positioning the tool, the outer limit of a particular "cut" occurs at the periphery of the tool. For example, plotting letters too close together will result in an engraving in which one letter merges into an adjacent letter. After making some of these mistakes, students should quickly realize the importance of carefully planning all activities of their projects in order to foresee potential problems.

It is expected that the immersion of students in these project-based manufacturing activities will provide pathways to future careers in manufacturing.

6.0 Conduits to Future Careers

Does the Manufacturing Technology Learning Module play a role in career selection?

The early introduction of Manufacturing Technology to the students could influence their career paths. The excitement of conceiving a design, using math and geometrical elements to express that design in an X-Y coordinate system, and translating the design into an NC program, may be the nudges they need for starting them along career paths as machinists, mechanical technicians, computer programmers, engineers, and production workers for programmable automation equipment.

High-profile careers such as athletes, actors/actresses, entertainers, certainly have an edge in terms of attracting youth. However, the fall-out rate along the road toward pursuing these careers is extremely high. To attract more youth to manufacturing, high-performance training and learning technology should be introduced early in the educational system. The major emphasis should be on learning applied math, integrated with high performance training technologies. This is exactly what this project is attempting to do. More innovations leading to high performance training/learning technology that could integrate applied math and with project-based activities are needed. The component technologies and the infrastructure are available and cost effective. The challenges are integrating the appropriate technologies and finding the application content that is compatible with the level of subject matter being studied. There is a need for more research to make application-based, high-performance, learning systems

accessible to grades K-4 through K-12 as well as to community colleges and technical schools. This need is accentuated by the high tech firms that continually lobby the U.S. government to admit immigrants with high tech-skills. With better preparation for U.S. students to enter high tech careers, there would be less need to import highly skilled workers and less displacement of U.S. workers. This would result in nationwide cost savings.

Project activities described in Section 3.0 are being used in this project as a means of applying math and as a means of integrating math and manufacturing technology. Some projects are shown in Figures B6 of Appendix B and C11 of Appendix C. These types of activities could lead to careers in engineering, computer programming, computer-aided design operators, computer-aided machining operators, machinist, computer-aided inspection operators, and operators for many other types of programmable automation equipment. Figure 4 shows a typical manufacturing facility with operators and programmable automation equipment. Also since this project-based activity makes an easy connection between classroom activities and the real world, this may be the impetus needed to make the students realize the importance of getting good education which includes some manufacturing technology.

Figure 4: PecWest Machine Shop, *Complementary of HAAS Automation, Inc.

*NOTE: The use of this photo does not imply the endorsement of this company's product.

Figure 4 shows a photo of a group of computer numerical control (CNC) machine tools that are being used in the manufacturing of component parts and tooling for research and development for the auto racing industry [8]. [It should be noted that the students write numerical control programs that run on a machine shown in Figure B-1 of Appendix B.

These NC programs are similar to the NC programs that run on the machines shown as shown in Figure 4.

Figure 5 shows component parts and tooling that were manufactured in the PecWest Machine Shop shown in Figure 4 [8].

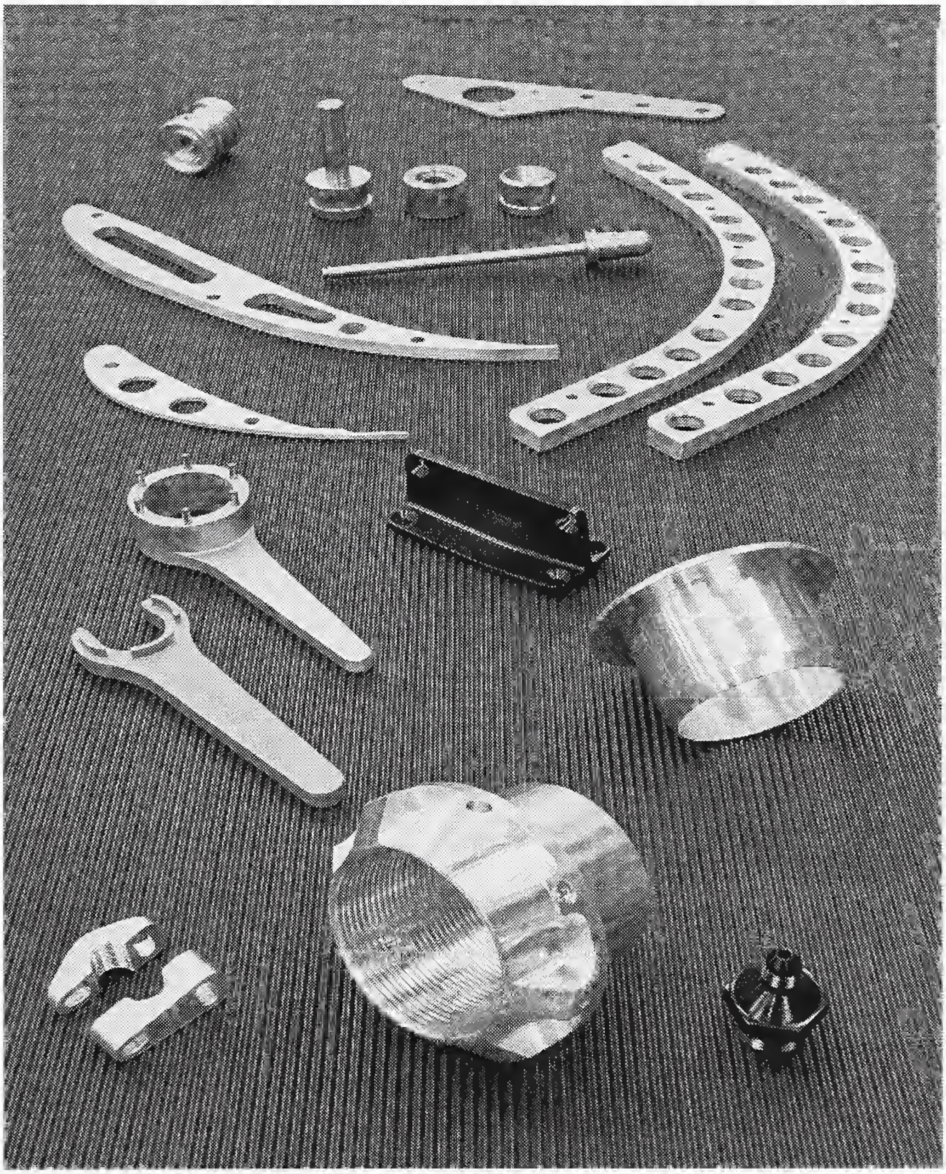

Figure 5: Samples of Component Parts and Tooling, *Complimentary of Haas Automation, Inc. [8]

Figure 6 shows a large CNC milling machine that is used for machining die components for automotive sheet metal stamping. The part being machined is called the "Lower Die Shoe". This Lower Die Shoe is fabricated from cast-iron material and it weighs several tons. It takes a few days to machine this part.

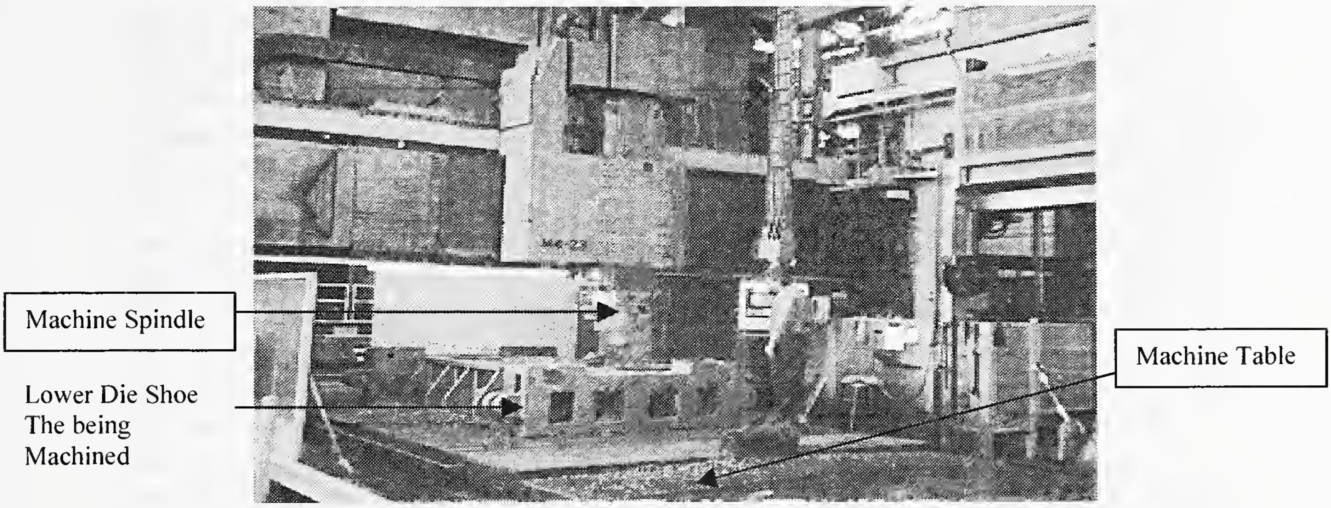

Figure 6: Three Axis CNC Milling Milling Machine, Complimentary of NAO Fabrication Division the General Motors Cooperation

7.0 Potential Uses and Future Research

The potential uses of learning modules and the research that is needed to develop new and improved modules are described in sections below.

7.1 Potential Uses

The MTLM Project is conducted during regular school hours. The Math Club and technology classes participate in the MTLM project. Most of the activities involved in this project are student-centered. Since students often work on their project independently, and occasionally require facilitation from the instructor, this project might also be well suited for special, after-school programs. Most of the required instructions can be conducted by demonstrating the machining simulation software. Additional instructions and demonstrations are obtained by using NC Tutoring software (Called NC Learn, see disclaimer on page ii). Online instruction could be made available via this project's Web site (**http://www.mtlm.nist.gov/**). Increasingly, more computer laboratories are being established in low-income housing facilities. Also, many religious organizations are establishing computer laboratories to provide computer access for the disadvantage. Since the MTLM project does not require on-going facilitation of an instructor, the MTLM project could be launched at these facilities, as a means of stimulating students' interest in learning math and technology. Competitions and awards could be established to recognize students who design and develop the NC program for the award winning projects. Students' projects that win these awards could be exhibited on the MTLM web-site. This would provide recognition for the students' accomplishments among peers, parents and relatives.

7.2 Description of Modules

Most of the research activities of the MTLM project focuses on adapting the technology so that it can be used and understood by students in grades 4 through 12 . The SBIR solicitation and other contractual efforts of this project provided funding and served as a catalyst for the development of learning-modules that facilitates student-centered learning environments. Figure 7 gives a brief overview of six learning-modules. Module 1 contains software for performing three-dimensional simulation of a 3-axes milling machine. It contains a NC programming work area for writing a NC program interactively. This software provides analysis tools for performing cross-sectioning of the blocks and the capability of measuring features of the simulated-machining of the blocks. Module 2 contains a series of lessons on programming straight-line moves and circular moves. Module 2 also contains a few lessons on determining the material removal for achieving the specific weight reduction of items proposed for machining. Module 3 is called the Personal Tutor and it is a software upgrade of module 1 to run on Windows 95 operating system. Module 3 contains more integration of the technology of machining with the NC programming. Module 4 is a multimedia software that includes theory and practice sessions for achieving machining efficiency and animation for demonstrating coordinate graphing and other basics in math. Figure C5 of Appendix C shows students

viewing a demonstration of Module 4 on the computer monitor. Module 5 is a machine tool "Visualizer". It provides a view of the interaction of various components within the machine, in response to various commands within the NC program. Module 6 provides case-based reasoning for an intelligent tutoring system. It provides an exploratory environment and it assesses the students' ability to use recently acquired knowledge to choose parameters that would correct a selected case of poor machining conditions. Module 6 is intended for apprentices. Modules 4, 5, and 6 were not completed because of a lack of funding. Module 4 is often used for demonstrations during laboratory visits. Although not completed, Module 4 is an outstanding accomplishment and it should be completed, if funds become available. Module 4 was developed by Seward Learning Systems, Inc, [9], located in Minneapolis MN. The main module of the MTLM project is Module 1. It is an interactive three-dimensional machining simulation software that is used by the students for writing their NC programs. Modules 1, 2, and 3 were developed by Vulcancraft, Inc. of Silver Spring Maryland [10].

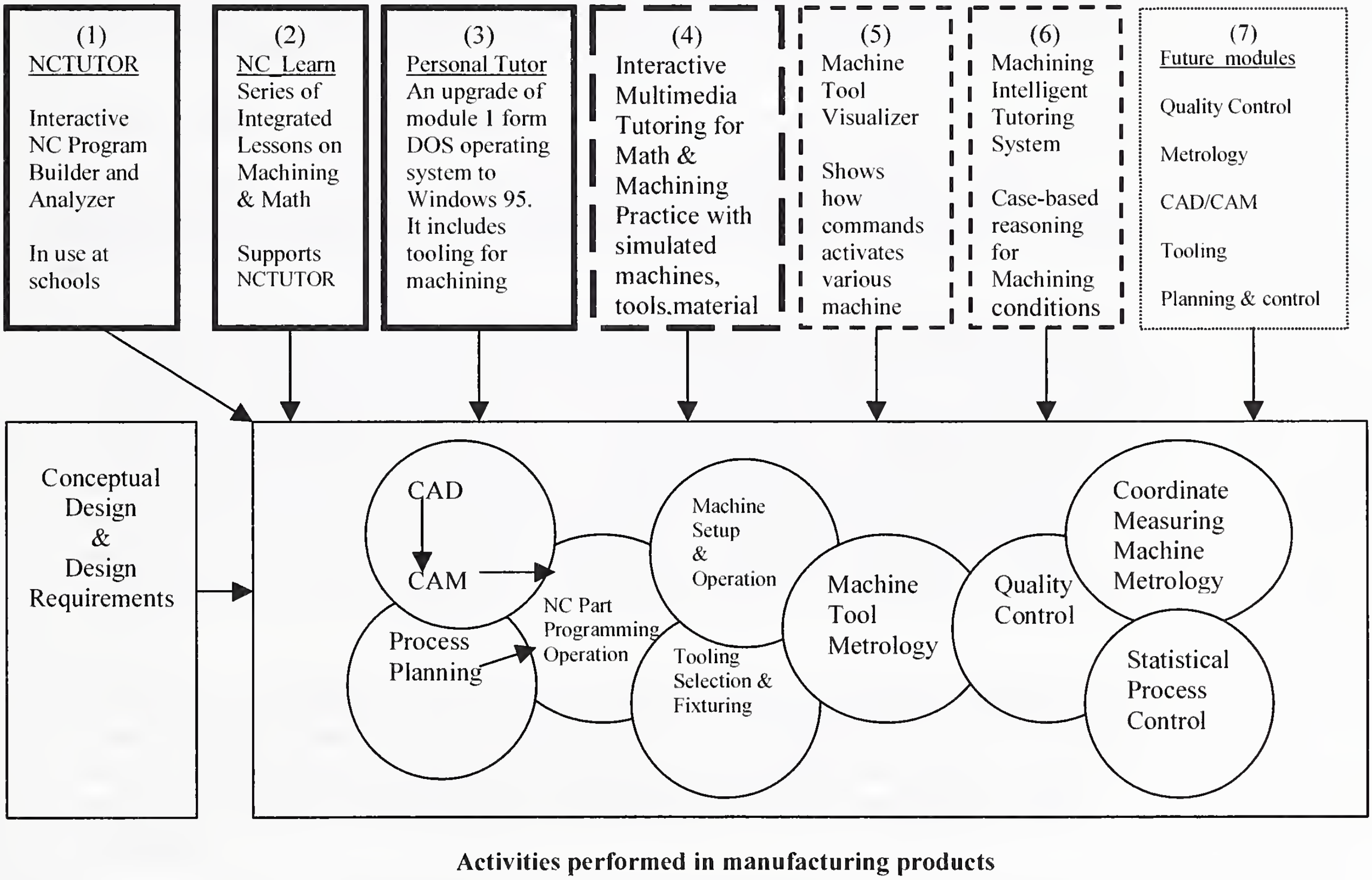

Figure 7. Manufacturing Technology Learning Modules

7.3 Future Research

The main focus of the modules 1, 2, 3 and 4 is on NC programming operations. These modules briefly treat the activities shown in Figure 7, such as process planning, machine setup and operations, tooling and fixturing and statistical process control. Research is needed to develop training modules that could provide more thorough treatment of these manufacturing activities. Also, research is needed to develop new modules to provide training for other manufacturing activities shown in Figure 7. For example, training for higher educational levels (grade 11 through junior college), modules could be developed for machine tool metrology and coordinate measuring machine (CMM) metrology. This would involve training for the use of measurement systems such as laser interferometry, ball-bars, leveling devices, capacitance-base sensors, and data acquisition systems . Training Modules for computer-aided design (CAD) and computer aided machining (CAM) are commercially available, but should be modified to be more suitable to grade levels as low as 9th grade. Research is needed to make the operation of some these modules accessible via the Internet. For example, Web-based operation of modules 1, 2, 3 and 4 could facilitate dissemination of these modules.

7.4 Opportunities for Future Learning

Training modules for some manufacturing activities displayed in Figure 7 offer significant opportunities for application-based learning. The following are a few possible examples of application-based learning:

- One of the major concerns of machine tool metrology is the heat generated during machining. The heat causes the machine components to expand. A machine's drive axis system may expand by different amounts. Expansion of some components could cause non-squareness of the machines coordinate axes. A transformation-matrix of the coordinate axes system is required to determine the true location of a point in a non-orthogonal (non-square) axes. This example would show the physics that describes the behavior of dissimilar materials and geometry for determining the transformation of coordinate axes. This could be a great opportunity for integrated learning for students in grades K12 through K14.

- Consider non-straightness motion of one machine axis with respect to another axis. Laser interferometers are often used to measure the straightness motion of a machine axis. Learning about the physics of interferometry could be included in a training module on machine tool metrology and coordinate measuring machine (CMM) metrology.

- The capability of a machine to execute precise circular motion is highly desirable. The lack of one axis to move at the commanded rate with respect to the commanded rate of another axis can produce following-errors that will lead to non-circularity. There are several facets of learning dealing circular motion and data manipulation for centering error.

- Machining productivity is often measured by material removal rate (MRR). MMR is determined by the three cutting conditions feed, speed and depth-of-cut. Balancing these cutting conditions to achieve the best MRR value while meeting specification could be a lesson in optimization, which is very important in process planning.

8.0 Summary

This Manufacturing Technology Learning Module project has demonstrated that it is practical to develop a learning module that uses learned fundamentals and to apply those fundamentals to an application that is linked to real world significance. This project is none-intrusive because the student does not have to learn a lot of new things in order to participate in the project-based activities; instead they build on the math that they have already learned. Activities performed in these projects enhance students' ability to visualize conceptual designs and help them plan their designs within a coordinate system. During the project-based activities, the students learn some of the basics of machining processes and numerical control programming. Students' excitement comes from the viewing the simulation of the machining process and the receipt of their machined wax blocks (the parts). The use of the Internet to transmit numerical control programs and digital images of the machined wax-blocks, provides an additional level of excitement for the students. The successful implementation of the MTLM project requires a highly motivated teacher and a supportive administration. Two companies, two teachers, two parents, and students provided favorable comments on this MTLM project. The comments from individuals of two companies suggested that the participation in this MTLM project could lead to meaningful careers in manufacturing and therefore the project should be expanded nationally. Participation in project-based activities could be the impetus that will attract students to become engineers, computer programmers, and skilled workers to operate programmable automation equipment. The future of U.S. competitiveness will depend on increasing the number people pursuing these types of careers. Finally, technology learning modules can be developed for any discipline and for any level. There is a need for innovative training modules. The cost trend for their development is favorable. However, greater acceptance will come about as the awareness of the value of these modules for accelerating the training and learning process grows. This author believes that this Manufacturing Technology Learning Module project is adaptable to after school programs and will seek opportunities to implement this project in an appropriate after school programs.

Reference:

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[2] Link R.U., Letter from Robert Link to C.D. Lovett, LinkGrear Company, June 1, 1998

[3] Bratkovich A.., Letter from Anthony Bratkovich to C. D. Lovett, Association of Manufacturing Technology, June 5, 1998

[4] Randall C., Letter from C. Randall to C. D. Lovett, Thomas Jefferson High School of Science and Technology, Alexandra VA, May 14, 1998

[5] Bush J., Letter from Jerry Bush to C.D. Lovett, Clearspring Elementary School, Damascus MD, May, 22,1998

[6] A group of Essays from 4th-grade Math Club Students, May 1998

[7] Principles & Standards for School Mathematics, Discussion Draft, National Council of Teachers of Mathematics, 1998

[8] Rathburn, S., CNC Machining, Haas Automation, Inc., p.14 Vol. 2, No 8, Winter1999

[9] Interactive 3-D Mathematics Instructions, SBIR Phase I Final Report, Seward Learning Systems, Inc. Minnaepolis, MN; December 1996

[10] An Interactive CNC Learning Experience ,Vulcancraft , Inc. Silver Spring, MD, February 1999

APPENDIX A
A listing of hardware and software

Hardware:

3-Axis milling machine with control module Box. See Figure B1 of Appendix B

486 PC computer for controlling the milling machine. See Figure B4 of Appendix B

486 PC computer for running 3D simulation software. See Figure B2 of Appendix B

486 Multimedia computer capturing and preparing images

Digital Camera

Software:

3D simulation & verification software for the 3-Axis milling machine

NCTUTOR; Simulates the tool motions of a milling machine. See Figure B2 of Appendix B

3D Tutoring Software for 3-Axis Milling machine

NC-LEARN; Provides tutoring for NC programming Uses interactive mini-projects to demonstrate principles

2-View verification software

Verify; Gives X-Y view and Z view of the simulated machining. See Figure B3 of Appendix B

Internet Browser:

Used for viewing the Web pages for the Manufacturing Technology Learning Modules

E-mail Software:

For receiving groups NC Programs from the schools

For transmitting digital images to the computers at the schools

Digital image capturing software:

For capturing the image from the digital camera

For croping, and adjusting as may be appropriate

APPENDIX B
A Collection of photos
For Equipment, Software in operation and projects

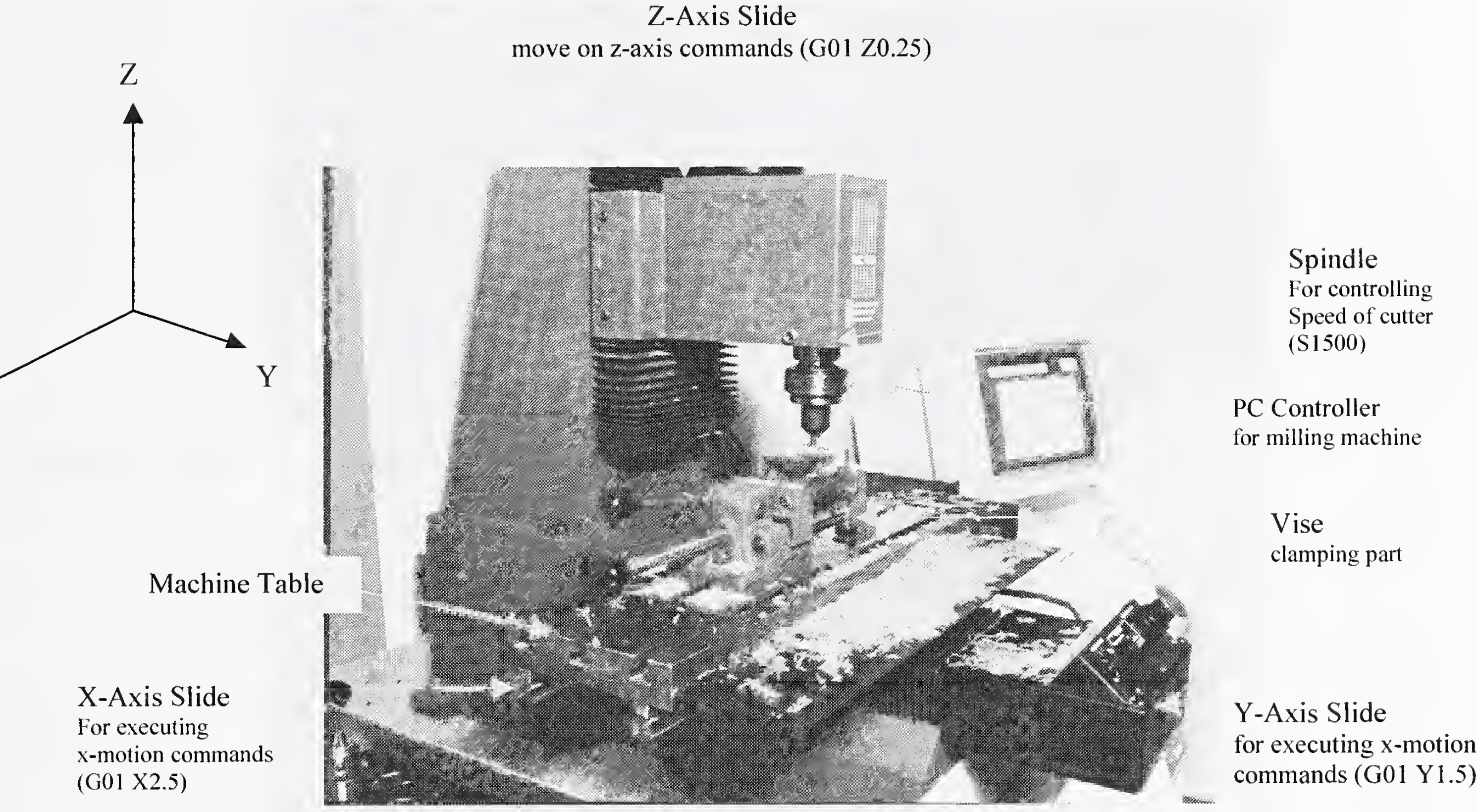

Figure B1: Three Axes Milling

Figure B2: Three Dimensional Machining Simulation Software

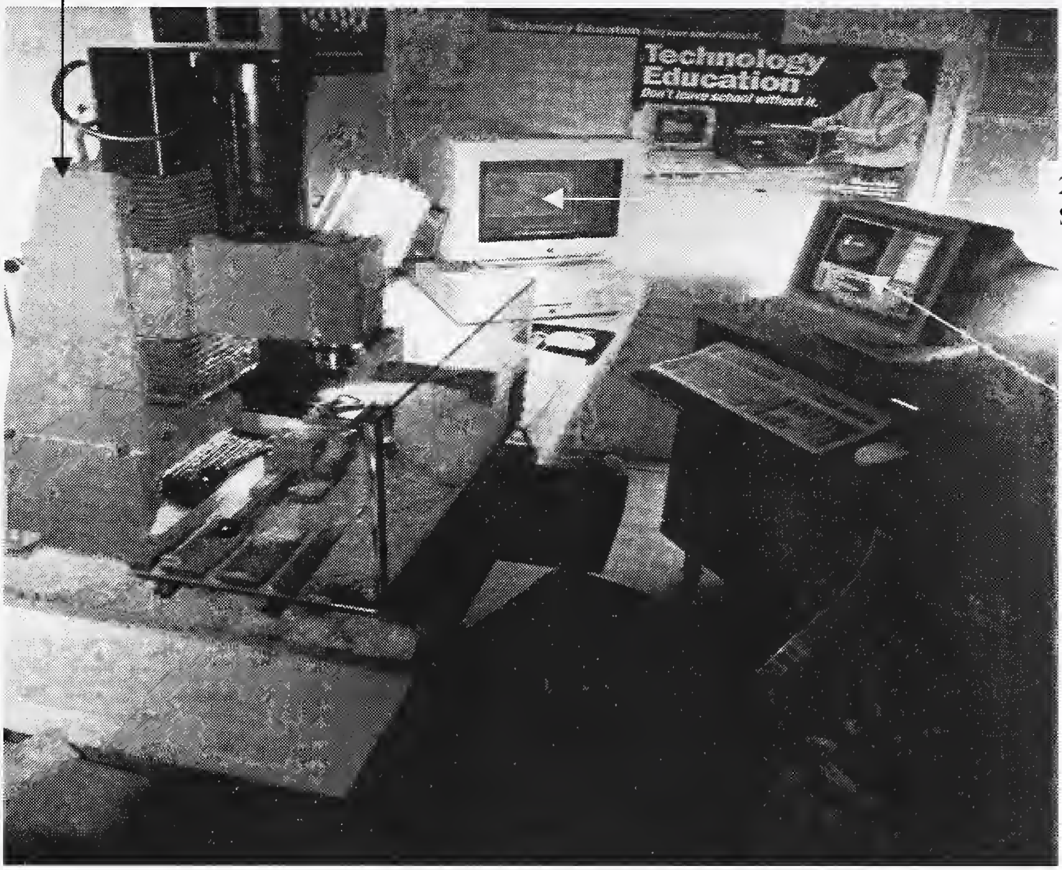

Figure B3: Machine Tool & Machining Simulation Software

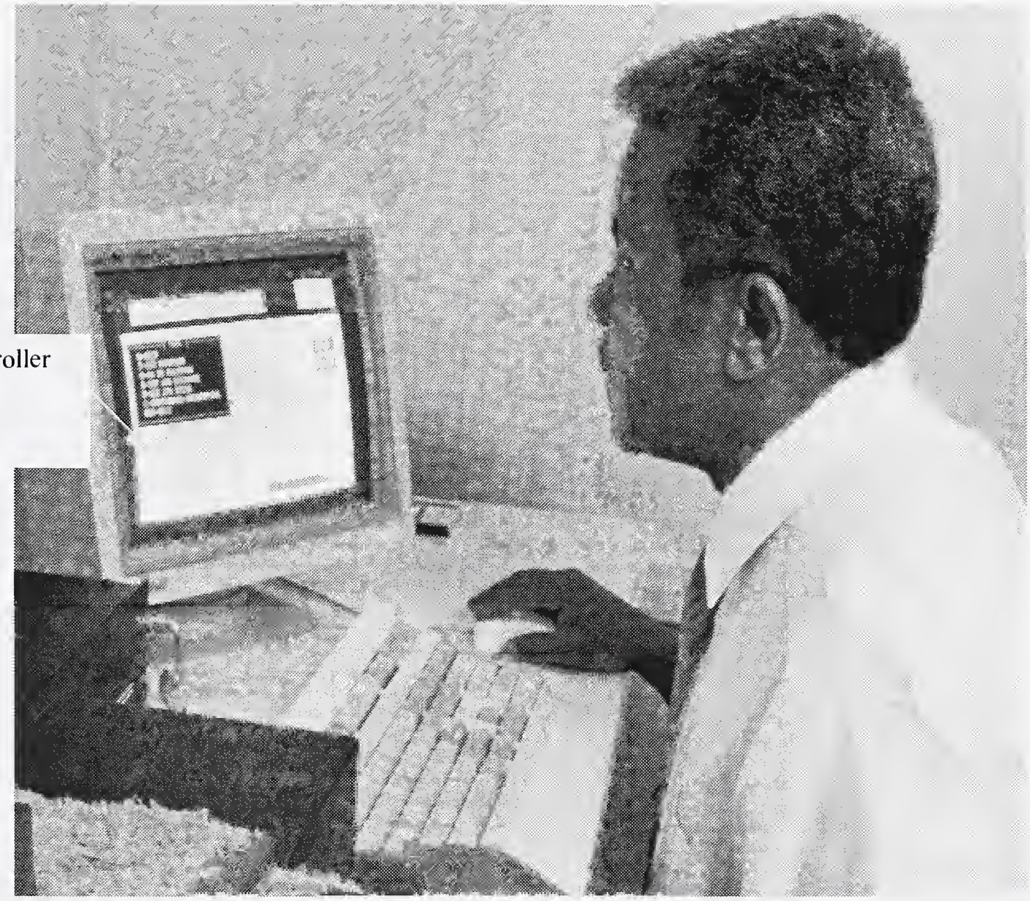

Figure B4: Controller and Software for positioning the machine

Figure B5: Students and Teacher at work on Project at School

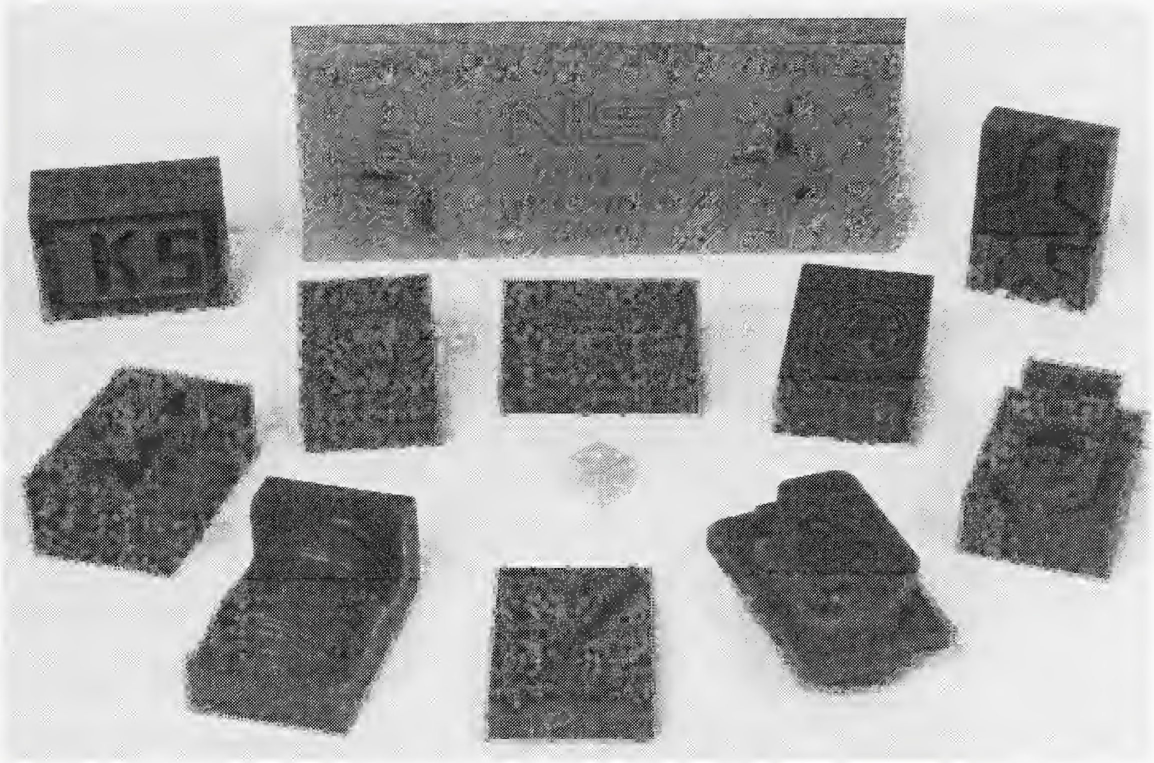

Figure B-6: A Collection of Projects

APPENDIX C

Shown below is an application for participating in Math Club at Clearspring Elementary School.

Math/Technology Club Application

Name: ______________________________

Grade: ______________________________

Teacher:______________________________

1. Please write or type one paragraph explaining why you are interested in being a member of the Math/Technology Club. Please be sure to tell what you think you could contribute to this club.

____

____

____

____

____

____

2. Please read and sign at the bottom:

A. I understand that I shall be responsible for making sure that any job I do for the Math/Technology Club will be done to the best of my abilities.

B. I understand that I am expected to attend the meetings, and to be one time.

C. I understand that I am expected to leave the building after the meetings, and to report to my home (or other designated location in accordance with written direction from my parent or guardian) upon leaving the building.

D. I understand that if I do not carry out my responsibilities I may be removed from the Math/Technology Club.

E. I understand that I must work well in small groups.

______________________________ ______________________________

Student Signature **Parent Signature**

*Please note that there is no transportation provided. Parents are responsible for making appropriate transportation arrangements.

<u>Deadline to apply is Thursday, January 28, 1999.</u>

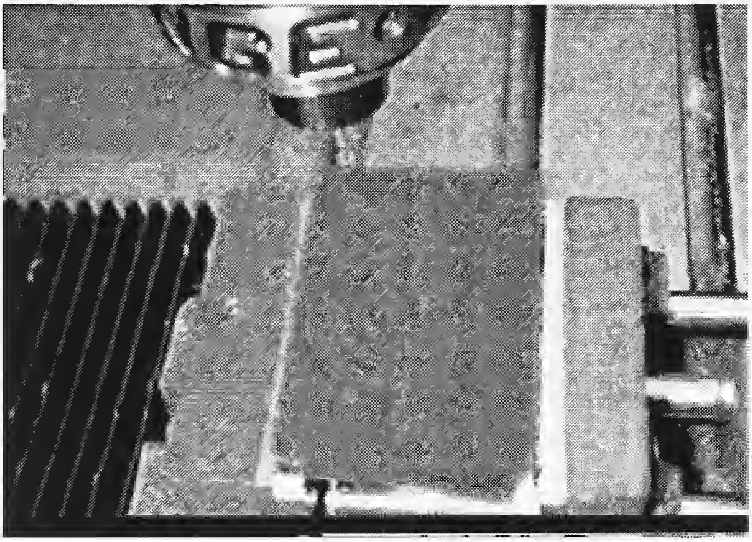

Figure C2: A student's Design and Milling

NC Program for the Design shown in Figure C2.

```
T1
G0X0Y0Z0.1F25.0M03 S2500
X1.2Y1.0
Z-.1
G90
G2
X1.8Y1.0I1.5J1.0
G1
Z.1
X2.0Y1.0
Z-.1
G90
G3
X1.0Y1.0I1.5J1.0
G1
Z.1
X.8Y1.0
Z-.1
G90
G2
X2.2Y1.0I1.5J1.0
G1
Z.1
X2.4Y1.0
Z-.1G90
G3
```

```
X.6Y1.0I1.5J1.0
X.4Y1.0I.5J1.0
X.2Y1.0I.3J1.0
X.2Y.8I.2J.9
X.2Y.6I.2J.7
X.4Y.6I.3J.6
X.6Y.6I.5J.6
X.8Y.6I.7J.6
X1.0Y.6I.9J.6
X1.2Y.6I1.1J.6
X1.4Y.6I1.3J.6
X1.4Y.8I1.4J.7
X1.4Y1.0I1.4J.9
X1.2Y1.0I1.3J1.0
X1.0Y1.0I1.1J1.0
X.8Y1.0I.9J1.0
X.6Y1.0I.7J1.0
G1
Z.1
X1.8Y1.0
Z-.1
G90
G3
X1.6Y1.0I1.7J1.0
X1.6Y.8I1.6J.9
X1.6Y.6I1.6J.7
X1.8Y.6I1.7J.6
X2.0Y.6I1.9J.6
X2.2Y.6I2.1J.6
X2.4Y.6I2.3J.6
X2.6Y.6I2.5J.6
X2.8Y.6I2.7J.6
X2.8Y.8I2.8J.7
X2.8Y1.0I2.8J.9
X2.6Y1.0I2.7J1.0
X2.4Y1.0I2.5J1.0
X2.2Y1.0I2.3J1.0
X2.0Y1.0I2.1J1.0
X1.8Y1.0I1.9J1.0
G1
Z.1
G0X0Y0
M02
```

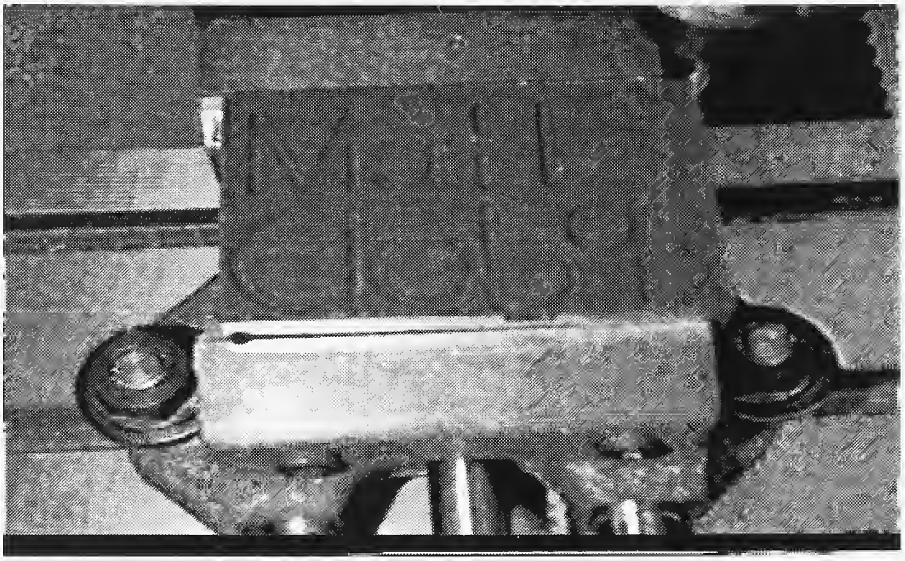

Figure C3: A Students Engraving for the Math Club

NC program for the engraving shown in Figure C3

```
T1
G1X0Y0Z0.1F25.0M03S2500
G90
X1.1Y1.5
Z-.1
X1.1Y1.5I1.1J1.3G2
G1
Z.1
X2Y1.1
Z-.1
X2.4Y1.1I2.2J0.9G2
G1
Z.1
X0.5Y0.9
Z-.1
X0.5Y0.1I0.5J0.5G3
G1
Z.1
X1Y0.6
Z-.1
X1.4Y0.6I1.2J0.4G3
G1
Z.1
X1.6Y0.5
Z-.1
X1.6Y0.1I1.8J0.3G2
G1
Z.1
X2.1Y0.7
Z-.1
X2.1Y0.7I2.3J0.7G3
```

```
G1
Z.1
X2.7Y0.9
Z-.1
X2.7Y0.9I2.7J0.7G2
G1
Z.1
X2.7Y0.5
Z-.1
X2.7Y0.5I2.7J0.3G2
G1
Z.1
G1
X0.2Y1.1
Z-.1
X0.2Y1.8
X0.5Y1.1
X0.8Y1.8
X0.8Y1.1
Z.1
X1.3Y1.5
Z-.1
X1.3Y1.1
Z.1
X1.6Y1.8
Z-.1
X1.6Y1.1
Z.1
X1.4Y1.5
Z-.1
X1.8Y1.5
Z.1
X2Y1.8
Z-.1
X2Y1.1
Z.1
X0.8Y0.9
Z-.1
X0.8Y0.1
Z.1
X1.6Y0.9
Z-.1
X1.6Y0.1
Z.1
X2.5Y0.9
Z-.1
X2.5Y0.1
Z.1
G0X0Y0
M02
```

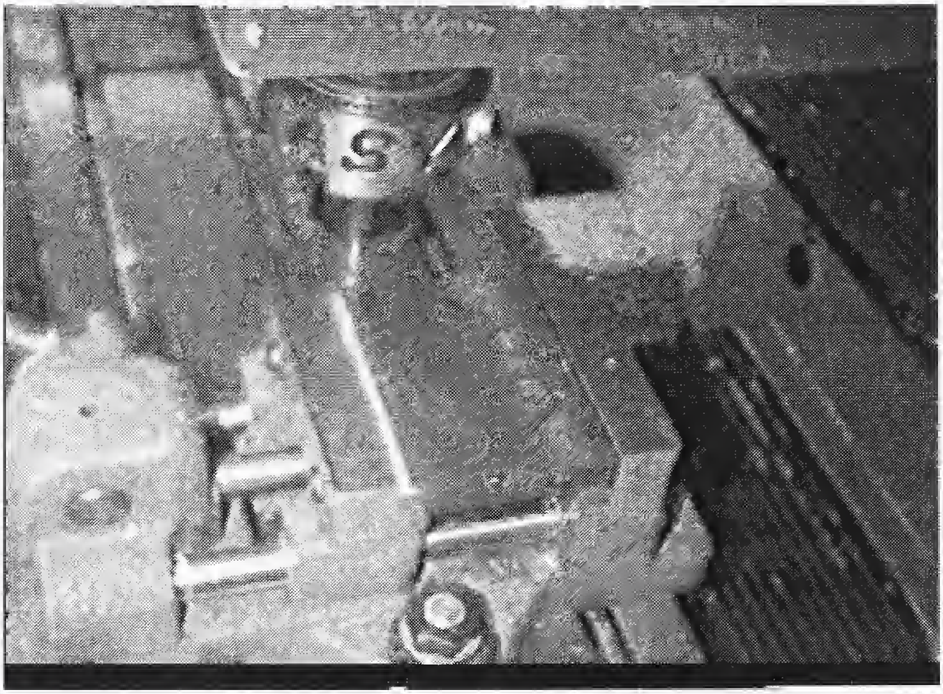

Figure C4: Design of a Smiling Face, by a student of the Math Club

NC Program for design shown in figure C4

```
T1
G1X0Y0Z0.1F25.0M03S2500
X1.5Y1.9
Z-.1
G03X1.5Y1.9I1.5J1.0
G01
Z.1
X1.1Y1.7
Z-.1
G03
X1.1Y1.7I1.1J1.5
G01
Z.1
X1.8Y1.7
Z-.1
G03
X1.8Y1.7I1.8J1.5
G01
Z.1
X1.0Y.8
Z-.1
G03
X2.0Y.8I1.
z.1G01
G0X0Y0
M02
```

Figure C5 shows the teacher observing students as students view the simulation for their NC program and a NIST apprentice demonstrates machining efficiency by adjusting cutting conditions.

Figure C5: Software for Module 1 and Module 4

Figure C6 : Math Club Students Showing Machined Parts during a visit to NIST

Figure C7: Students and Teacher During a Visit to NIST

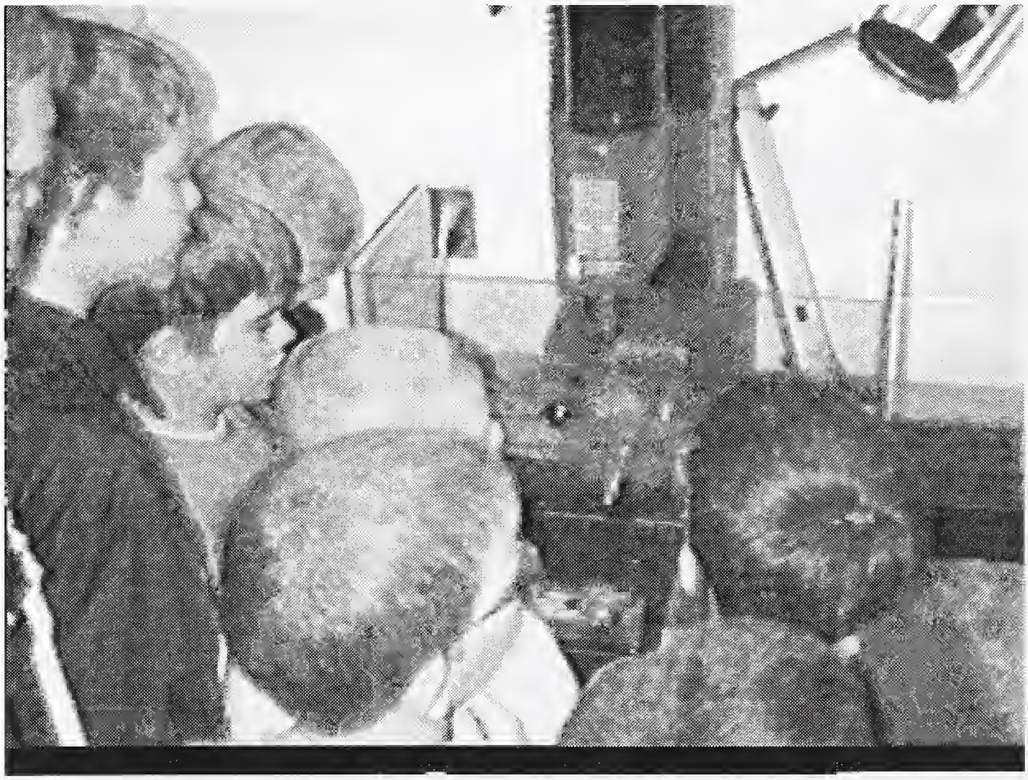

Figure C8: Math Club observing the machining operation
During a Visit to NIST

Figure C9: Students Showing Their Machined Blocks

Figure C10, shows the Math Club during a visit to NIST. The students attentively listen to the explanation about the grinding machine.

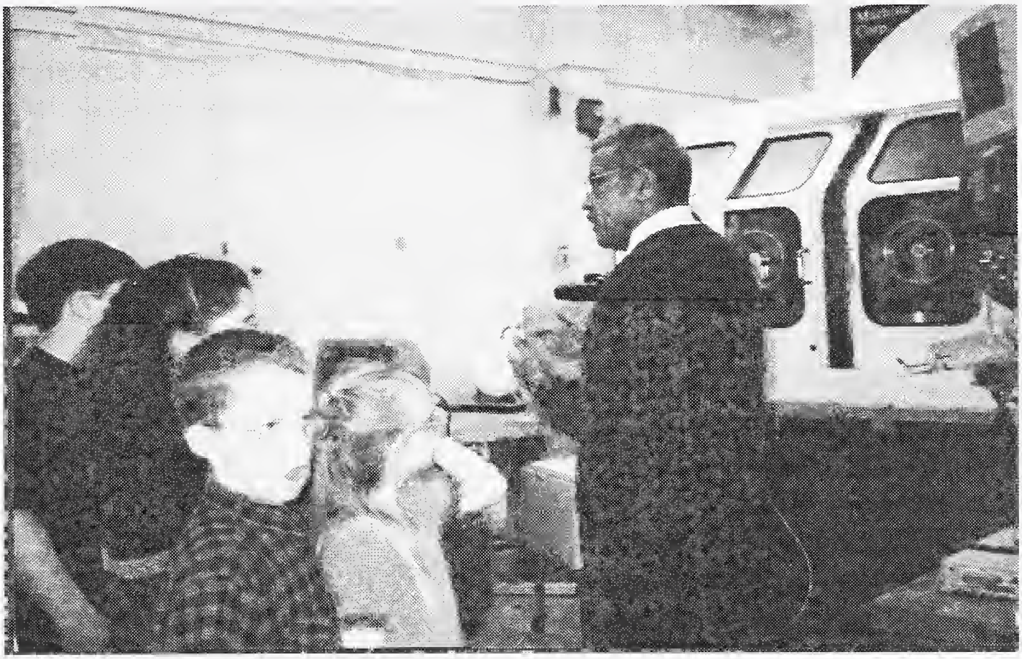

Figure C10: Math Club Tour of NIST

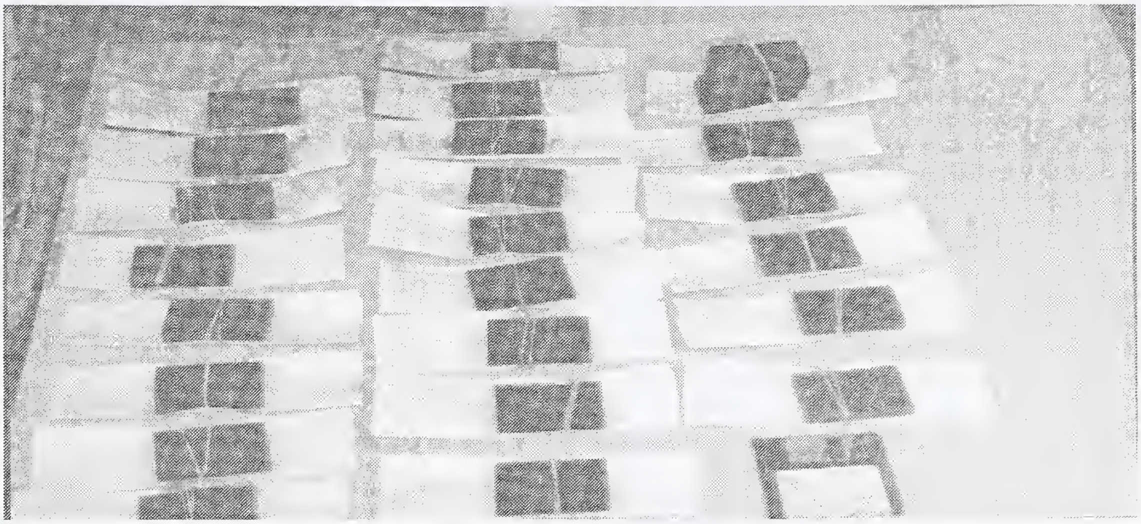

Figure C11: A Collection of Machined Blocks, being returned to Math Club at Clearspring Elementary School

Shown in Figure C11is a group of projects performed by the fourth grade math club at Clearspring Elementary School. These projects were machined on blue wax blocks and a copy of the NC program is attached to each project. Occasionally Correction to Numerical Control code is made. The corrected code is saved on diskette and returned to the instructor.